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COMPARISONS

BETWEEN THE

DIFFERENT SYSTEMS

OF

DISTRIBUTING ELECTRICITY

BY

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REMOTE STORAGE

COMPARISONS

BETWEEN THE

DIFFERENT SYSTEMS OF DISTRIBUTING ELECTRICITY.

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In advising various Authorities as to the most suitable system for an installation of electric lighting in their districts, I have found it impossible to give, in a Report of moderate length, the reasons which lead to the conclusions and opinions contained therein. I have therefore thought it would be useful to Authorities whom I am advising, if I set forth in a separate statement the data which govern the consideration of the subject. In comparing the different systems of electric lighting, it is indispensably necessary that the data should be based on conditions which are those that are likely to arise in practice, and on estimates worked out on equally liberal scales of prices.

The choice of a system depends upon the following conditions:—

(*a*) The probable demand, both at the outset and in the future.

(*b*) The geographical distribution of the demand.

(*c*) The nature of the demand, and the length of time during which the current is likely to be required.

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The systems may be divided into two classes:—

I. The "Continuous Current."
II. The "Alternating Current."

The term "Continuous Current" is applied to a current which is passed continuously in one direction through the lamps, while with the "Alternating Current" the direction of the current is reversed generally about one hundred times per second. Both systems produce the same amount of light from a given amount of energy actually expended in the lamps. The difference between the systems lies in the manner of conveying the energy from the central station to the lamps.

The ordinary incandescent electric lamp can only be worked at pressures not exceeding 110 volts, and it is not economical to convey current long distances at such a low pressure. As a general proposition it may be stated that the higher the pressure the more economically can the electrical energy be conveyed from one point to another. One way of increasing the working pressure is to place two lamps in "series" and then to distribute the current at 220 volts pressure instead of 110. This is the principle cf what is called "The Three-wire System," and it can be applied to both continuous and alternating current distribution. The same principle may be extended by placing three or four lamps in "series" and raising the pressure to 330 or 440 volts, this latter being called the "Five-wire System."

Another way of increasing the pressure to economise in the distribution, is to generate the current at very high pressures, and to transmit it at this high pressure from the central station to some point near the lamps, and there to "transform" it down to the low pressure suitable for working the lamps. With the continuous current, the "transformation" can be effected by employing a high tension current to work a motor, which drives a dynamo to generate another current at the required low pressure. These transformers can be made to give out, at low pressure, from 81 to 85 per cent. of the energy that is supplied to them at high pressure when working at full load, but at lighter loads the efficiency is much less.

Alternating currents can be transformed from one pressure to another by a "Transformer" or "Converter," which consists of two coils of wire wound through a core of iron plates or strips. The high tension current passes through one coil, and the reversals of direction in the current induce certain magnetic changes in the iron core, which, in turn, induce another alternating current in the second coil of wire, the relative pressures of the two currents depending upon the proportions of the two coils of wire. These transformers are much more efficient and much cheaper than continuous current transformers. Small transformers sufficient to work lamps in one private house, can be made to give an efficiency of about 93 per cent. at full load; and large transformers, sufficient to serve twenty-five houses or more, can be made to give an efficiency of about 97½ per cent. at full load.

The current in the primary coil varies as lamps are connected to the secondary coil, but if all the lamps are switched off, there is still a certain loss going on so long as the transformer is connected to the primary mains. This perpetual waste of power amounts to 3½ or 4 per cent. of the full load in small house transformers, but with very large sizes the waste can be reduced to about 1 per cent. of the full load.

The continuous current and the alternating current systems, may be divided under the following heads:—

CONTINUOUS CURRENT.

A. Two-wire System. Direct supply at 110 volts or less.

B. Three-wire System. Direct supply at about 220 volts.

C. Five-wire System. Direct supply at about 440 volts.

D. Continuous Current Transformer System. Current generated at about 1000 volts, and transformed at sub-stations to feed into low tension distributing mains.

Note.—Storage batteries may be used in combination with any of the foregoing.

ALTERNATING CURRENT.

A. The House Transformer System. Current generated at from 1000 to 2500 volts and transformed down to 50 or 100 volts by small transformers placed on each consumer's premises.

B. The Sub-station Transformer System. Current generated at 1000 to 2500 volts, and transformed at sub-stations by large transformers feeding into low tension distributing mains.

Note.—As storage batteries cannot be charged with alternating currents, the machinery must be kept running continuously, whether there is a profitable demand to meet or not. The alternating current is not so satisfactory for motive power as the continuous current.

The "Distributing Mains" are those to which the house connections are made, and the "Feeders" are conductors carrying current from the generating station to distant points on the distributing mains without having any current drawn off en route. The pressure in the distributing mains has to be kept constant within a small percentage, and it is found more economical to work the feeders with a larger percentage of variation, the pressure being regulated according to the amount of current passing, so as to maintain the required standard pressure at the distant points where the distributing mains are fed.

Where high tension currents are used and transformed at sub-stations, the high tension conductors may be regarded as " Feeders."

Continuous Current System A.

The continuous current system A (namely, the two-wire direct supply) is suitable only for private installations and for very small districts. Practically speaking it may be left out of consideration in dealing with the distribution of electricity over districts or towns.

Continuous Current System B.

The continuous current system B (namely the three-wire direct supply at about 220 volts) is the most usual method of employing continuous current. It is very economical and easy to work where the *average** length of feeders is less than three-quarters of a mile.

Continuous Current System C.

The continuous current system C may be used with advantage where there is a large demand at an average distance not exceeding one mile from the central station. It is a little more complicated than the three-wire system, and requires special arrangements for regulating the pressure which are somewhat costly in comparison to those of the three-wire system, unless the demand is very large, in which case the cost becomes insignificant.

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* See the definition of "average," on p. 11.

Continuous Current System D.

The continuous current system D cannot compete with others by itself, but it is very useful in combination with the three-wire system to serve outlying portions of a district where the demand is small.

Alternating Current System A.

The alternating current system A may be used with advantage only where the demand is distributed over a very straggling district, and where the lights are required for long periods of time. The perpetual waste going on in small transformers is a very serious drawback to this system in any place where coal is expensive. In the case of a demand arising chiefly in shops, the all year round efficiency of distribution is only about 66 per cent., so that the central station plant has to generate about 50 per cent. more energy than the lamps actually require. In a residential district the all year round efficiency is even less. It may be taken that at the present time private consumers use their lamps only for from 100 to 400 hours per annum, and the probability is that the general average will tend towards the lower figure as people learn to economise by switching off lights when they are not actually required. This tendency is fatal to economy in supply by the house transformer system in residential districts. Taking the demand as equivalent to 400 hours run per annum at full load (which demand is spread over about 2000 hours in varying proportions), the all year round efficiency works out at only 54 per cent., consequently for every 1000 units delivered to the lamps, 1850 units have to be generated by the central station plant. Again, taking a demand equivalent to 100 hours run per annum at full load, the all year round efficiency comes out at only 23 per cent., so that the central station plant would have to generate more than four times as much energy as the lamps require. The only argument in favour of the adoption of this system is in the smaller capital outlay involved owing to the absence of costly low tension distributing mains, and consequently in the facility with which a small demand that is scattered over a straggling district can be met with a moderate capital outlay. This system, however, cannot possibly compete with other systems in the long run, and for populous districts it may be practically regarded as being quite obsolete, although it is used by several companies in London, whose main object in adopting it was to obtain a hold over as large an area as possible with the minimum expenditure of capital.

ALTERNATING CURRENT SYSTEM B.

The alternating current system B is a very great improvement on the first, the superiority being entirely due to the use of large transformers in place of small ones, and in supplying a large number of consumers from one transformer, which need not be capable of serving simultaneously the total number of lamps installed, whereas a transformer in a house must be capable of serving the whole of the lights simultaneously, although it may only be required to do so once or twice a year. The aggregate demand in a district never exceeds 75 per cent. of the lamps installed, and in some districts (particularly residential districts) only one-half or a third of the lamps are ever used simultaneously ; the result is that whereas there is a perpetual waste in the house transformer system representing 3½ or 4 per cent. of the power required to run all the lamps simultaneously, there is in the sub-station transformer system a perpetual waste of only about 1 per cent. of the power required to run from one-third to three-fourths of the lamps simultaneously.

The low tension distributing mains may be laid on the three-wire system. They cost about the same as similar mains for continuous current, or slightly more, owing to the necessity for surrounding the conductors with an iron case to prevent the alternating current affecting any neighbouring telephone or telegraph wires. For the purposes of a general comparison between the best alternating current system and the best continuous current system, it may be assumed that both of them require a network of low tension distributing mains, which will be approximately equal in cost.

In some instances it may be desirable to combine the house transformer system with the sub-station transformer system, using the former to serve small demands in outlying parts of a district in which the bulk of the supply is served by the latter system.

In cases where the average length of feeders exceeds one mile, the alternating transformer sub-station system is undoubtedly the most economical for electric lighting purposes; but the question arises as to whether it is economical in any instance to serve a district with a central station so far away from the demand. This resolves itself into the consideration of the question as to whether it is economical to serve a large district entirely from one station, or from two or more smaller stations. It is very frequently asserted that the cost of running one station is much less than the cost of running two or more of the same aggregate power, and also that by using high tension currents the station may be placed in some very favourable position for obtaining coal, water, &c., which may be far removed from the centre of the district to be served. These advantages have been, and still are, greatly exaggerated, and entirely fallacious views are put forward about them. In some instances the site for a station has been chosen with a view to save from 10 to 20 per cent. in the price of coal delivered, when eventually the cost of coal consumed turns out to be greater owing to the greater losses in distribution. Interest on the extra capital, and depreciation, &c., on the main feeders, will often exceed the anticipated saving due to cheaper coal.

With a view to give a clear idea as to the best system to use in particular cases, some examples will be given.

The term "average length of feeders" is used to mean the average distance travelled by the current before being delivered into the distributing mains. The maximum length of feeder may be double the average, or even more, and the most distant lamps may be 300 or 400 yards beyond the end of the longest feeder. This point is frequently lost sight of in comparing high and low tension systems, and erroneous conclusions are arrived at, owing to calculations based on the *maximum* length of feeder being taken in place of the *average* as defined above.

The capacity of the station is stated in kilowatts. One kilowatt is capable of delivering one Board of Trade unit per hour to the lamps. Thus a 300 kilowatt station means one which can deliver 300 units per hour to the lamps.

One Board of Trade unit is sufficient to work a 16 candle-power lamp for 17 or 18 hours, consequently, the number of lamps which a station can serve simultaneously may be found by multiplying the kilowatts by 17 or 18. Thus a 300 kilowatt station will serve 5100 to 5400 lamps of 16 candle-power simultaneously; this may represent from 6800 to 10,000 or more lamps fixed according to the character of the district.

Example No. 1.

Average length of feeders, less than ¾ mile.

Service required, 1000 kilowatts or less.

The most economical system in total annual cost (i. e. including interest on capital, working expenses, maintenance, and depreciation) is the continuous current three-wire system, with a small reserve of storage batteries to maintain the supply during periods of light load.

The alternating system can be carried out at a slightly less capital cost if the average length of the feeders exceeds 600 yards, but the working expenses are so much greater that the total annual cost exceeds that of a continuous current system.

Example No. 2.

Average length of feeders, less than ¾ mile.

Service required, 1000 to 2000 kilowatts.

The most economical system will be the three-wire or five-wire continuous current systems, with or without a reserve of storage batteries for the light load.

Example No. 3.

Average length of feeders, from ¾ to 1 mile.

Service required, 2000 kilowatts or more.

The most economical system will be the five-wire system. The alternating transformer system comes second, and the three-wire continuous current third, in order of economy in total annual cost. The alternating system would cost slightly less than the five-wire system in capital outlay, but this is more than counterbalanced by the heavier working expenses of the alternating system.

Example No. 4.

Average length of feeders, more than 1 mile.

Service required, 200 kilowatts or more.

The most economical system, both in capital cost and in total annual cost, will be the alternating transformer system.

Note.—If the demand exceeds 1500 kilowatts, it would be cheaper to serve this district with two or more stations instead of one, as shown in Example No. 6.

Example No. 5 (A *and* B).

A district about 2½ miles long, requiring a service of 300 kilowatts.

5 A. If at least two-thirds of the demand can be served direct from the central station with feeders *averaging* not more than half a mile in length, the most economical system would be the continuous current three-wire system, combined with continuous current transformer sub-stations to serve the small demand at a distance of more than one mile, and with a reserve of storage batteries to serve the light load work. In special cases it might be

better to use the three-wire direct supply throughout, with the batteries placed in sub-stations at the ends of the longest feeders.

5 B. If only one-third of the demand can be reached by feeders averaging half a mile in length, the alternating current system would be the best, as the saving in interest on capital, &c., will be sufficient to overbalance the cost of running the machinery continuously.

Example No. 6.

A district about 3 miles long requires a service of 1,250 kilowatts at the outset, increasing to 2,500 kilowatts in a few years and afterwards to 5,000 kilowatts.

Leaving out of consideration the low tension distributing mains, which would be required for both continuous and alternating systems, the following comparison is based upon the cost of central stations, feeders, and sub-stations, as regards capital and interest on that capital, depreciation of the works, cost of energy wasted in distribution, and additional cost of wages involved by working more than one station.

The cost of central stations is taken to be £2,500 + £45 per kilowatt for the alternating current system. For the continuous current system it is taken at £2,500 + £50 per kilowatt with feeders averaging half a mile long, and £2,500 + £46 per kilowatt with feeders averaging one quarter of a mile long. The difference is due to the inferior efficiency of the continuous current system at full load when the feeder exceeds one quarter of a mile in length. In both cases, however, the extra capital required to erect two stations in place of one is about £2,500. The cost of continuous current feeders half a mile long is about £14 per kilowatt, and the cost of high tension alternating current feeders half a mile long is about £8 per kilowatt, and the sub-stations with alternating transformers cost about £6 per kilowatt. Interest on capital is taken at 5 per cent; depreciation at 6 per cent. on central stations, 2½ per cent. on feeders, and 15 per cent. on alternating transformers. The extra wages and miscellaneous expenses involved by working two stations instead of one are taken at £750 per annum. The output is calculated on a "load factor" of 10 per cent., which is equivalent to a run of 880 hours per annum at full load. The all year round efficiency of distribution is taken at 88 per cent. for the alternating current system, and 95 per cent. for the continuous current system, with feeders averaging half a mile long. The cost of the energy wasted in distribution is taken at 2*d.* per Board of Trade unit. It is assumed that the average length of the feeders will be one mile if the district is served from one station; half a mile if it is served from two stations; and one-third of a mile if it is served from three stations.

The following Table gives the capital outlay in respect of central stations, sub-stations, and feeders, and the total annual cost of all the above mentioned items which affect the comparison:—

	Capital Outlay. £	Annual Cost. £
1250 KILOWATT SERVICE:		
*One alternating current station ..	86,250 ..	10,760
Two alternating current stations ..	78,750 ..	11,040
†Two continuous current stations ..	85,000 ..	9,990
Three continuous current stations ..	81,900 ..	10,470
2500 KILOWATT SERVICE:		
One alternating current station ..	170,000 ..	21,250
*Two alternating current stations ..	152,500 ..	20,775
Two continuous current stations ..	165,000 ..	18,675
†Three continuous current stations ..	156,300 ..	18,520

* The best arrangements with alternating current.

† The best arrangements with continuous current.

5000 Kilowatt Service:	Capital Outlay. £		Annual Cost. £
One alternating current station ..	337,500	..	42,175
*Two alternating current stations ..	300,000	..	40,250
*Three alternating current stations ..	289,200	..	40,280
Two continuous current stations ..	325,000	..	36,050
†Three continuous current stations ..	305,100	..	34,730

An examination of the above Table will show that the 1250 kilowatt service can be carried on more economically both as regards capital outlay and annual cost, by two continuous current stations than by one alternating current station.

The 2500 kilowatt service can be carried on by two alternating current stations more economically than by one alternating current station, and still more economically by two or three continuous current stations.

The 5000 kilowatt service can be carried on by two or three alternating current stations better than by one alternating current station, but the work could be very much more economically performed by three continuous current stations.

In every case therefore it is clear that a district of this magnitude can be supplied by two or three continuous current stations more economically than by any alternating current system. Moreover the capital outlay for the best arrangement with the alternating system differs very slightly from that of the best continuous current arrangement, and where the alternating current capital comes out the smaller of the two, the saving in annual cost by the continuous current system will entirely cover the difference in less than three years. In this comparison

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* The best arrangements with alternating current.

† The best arrangement with continuous current.

the continuous current has been calculated on the three-wire system throughout. The 5000 kilowatt service could however be more economically worked by the five-wire system, which can be introduced and grafted on to what was previously the three-wire system without the slightest difficulty. The capital cost with that arrangement would then be considerably less than with the alternating current system, and the annual saving would be more than £6000.

The output has been assumed to be the same for the two systems, but there is very little doubt that an installation for electric lighting on the continuous current system has a much better future for motive power purposes than one that is on the alternating current system. At the present time the question of motive power is coming to the front, and will be a very important branch of the business of electric supply undertakings when the works reach a sufficiently large size to enable the price of the current to be reduced below 6*d.* per unit as a maximum price, and to permit the introduction of a sliding scale of charges which would work out to less than 3*d.* per unit for consumers who require current all day long. The continuous current system has a large field for renumerative business in this direction, as there is great competition in the manufacture of thoroughly satisfactory electric motors, whereas the same cannot be said of alternating current motors.

Another very strong reason for preferring continuous current is that it can be used for charging storage batteries, and they open another field for augumenting the "Load Factor" on the central station which is not open to alternating current systems.

Batteries in Sub-stations, to assist during Periods of Maximum Demand.

A continuous current station, with feeders averaging half a mile in length, costs from £65 to £70 per kilowatt for central station plant and feeders on the average, but the longest distance service ($\frac{3}{4}$ mile to 1 mile from the station) costs from £85 to £100 per kilowatt. In such cases it becomes a question whether batteries cannot be profitably used in sub-stations, to augment the capacity of the long distance service plant and feeders.

Battery sub-stations can be erected and fitted with all the necessary appliances for charging and discharging, at a cost of £100 per kilowatt, taking the period of discharge as 10 hours. The same batteries can be discharged at double the rate for 4 hours, so on this basis the cost is only £50 per kilowatt. It is not probable that the maximum load would ever remain on the station for more than 6 hours continuously. For the purposes of the following comparison, it is assumed that the cost of battery stations would be £70 per kilowatt.

The loss of energy in the batteries may be taken at about one-third, but the energy put into them would all be generated at times when the station is not fully loaded, and would involve very little if any additional labour at the central station. The saving in labour per unit generated would more than cover the losses in the batteries.

The following comparison depends only on the relative amounts to cover interest on capital, maintenance and depreciation.

Additional central station plant and feeders, costing

£100 per kilowatt, involves an annual cost of £9·6 per kilowatt per annum.

A battery sub-station costing £70 per kilowatt, involves an annual cost of £11·3 per kilowatt per annum, including the high rate of 15 per cent. for depreciation on the storage cells.

These figures show that although the batteries save 30 per cent. in capital, the heavy cost of maintenance overbalances that advantage.

In a few years time, however, the comparison will be different, as improvements are being made which tend to make batteries cheaper and more durable. It is practically certain that the cost will be reduced below £60 per kilowatt, and the maintenance below 10 per cent., thus reducing the annual cost to less than £7·8 per kilowatt, or considerably less than the cost with additional central station plant and feeders.

The corresponding figure in the case of the alternating current system, with feeders about one mile long, would be about £9 per kilowatt per annum.

The saving in labour per unit produced at the central station, due to working the machinery at a good load during the day to charge batteries, tells largely in favour of using battery sub-stations. In the case of residential districts, where the producing capacity of a station may be trebled by the addition of battery sub-stations, the £7·8 per kilowatt will be much reduced.

Some battery makers already contend that the cost of maintenance is less than 10 per cent., but even if this is conceded, it still remains better policy to defer for a few years spending large sums on batteries, to increase the capacity of works, in order to take advantage of improvements which are sure to be made. There is no prospect of corresponding improvements in central station generating plant.

Central station plant lies idle for very long periods of time. The output during the year under ordinary conditions at the present time only amounts to about one-tenth of what it might be if the machinery ran continuously at full load, and even in foggy days in winter in business districts the output never reaches the equivalent of 12 hours run at full load. In residential districts the maximum output in any one day probably never reaches the equivalent of 8 hours run at full load. It follows therefore that central station plant could be made to generate two or three times as much electricity if storage batteries were provided at sub-stations. This affords a convenient mode of doubling or trebling the capacity of continuous current stations in the future without incurring any expenditure at the outset to facilitate extensions later on. The battery stations can be erected in any positions where the demand requires fresh provision to be made, and can be connected to the distributing mains from which the storage cells would be charged during periods of light load.

RATE OF INTEREST ON CAPITAL.

In the comparisons given, the rate of interest upon capital has been taken at 5 per cent. in every case. If other rates were taken the results would be slightly different.

Most Local Authorities can borrow money at 3½ per cent., and at this low rate of interest the difference in comparative annual cost tells slightly in favour of the system which involves the largest capital outlay. In the case of a company seeking 10 per cent. dividends, the comparative annual costs must be modified slightly in favour of the system which requires the smallest capital outlay.

The cost of working an installation by a Local Authority is often compared with that under a company, without bearing in mind that the Authority is paying off its capital while the company is not. A Local Authority can pay off its capital in 25 years with 3½ per cent. interest, in annual instalments amounting to only 6·06 per cent. on the capital, or in 42 years in instalments of 4·6 per cent. on the capital.

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